Analysis, Prediction and Control of Radio Frequency Interference with Respect to the DSN

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The objective of this report is to inform the reader about four aspects of analysis, prediction, and control of RFI with respect to the DSN. The four aspects are: susceptibility modelling, prediction of RFI from satellites, operational RFI control and international regulations. Special emphasis is given to the existing satellite interference prediction program called DSIP2. This report is intended to be a tutorial for those not familiar with all of the covered topics and also to provide a summary status evaluation from the author's point of view. The report is also expected to serve as a catalyst in guiding future work.

Principal conclusions of the report are:

(1) Analytic modelling and laboratory verification of DSN receiver susceptibility to RFI should continue, this being useful for RFI analysis and prediction, and the setting of regulatory protection criteria.

(2) The performance of the satellite interference prediction program needs to be tested and assessed to determine the need for and kind of refinement that would be effective.

(3) Existing operational management organizations and methods are effective in controlling Goldstone RFI and should continue. The Electromagnetic Compatibility Analysis Center has been independently modelling DSN susceptibility to RFI. Continuation of this effort is not recommended.

(4) Continued participation in organizations that influence and control international use of radio frequency bands is deemed essential with respect to the setting of protection criteria for deep-space telecommunications.

I. Background

In the mid 1970's the DSN experienced an increase in radio frequency interference (RFI). Some of the interference caused degradation or outage of data from deep-space missions. The trend of RFI events suggested the need for:

(1) A better understanding of the susceptibility of DSN earth stations to RFI.

(2) Development of a capability to predict RFI occurrences from known signal sources.

(3) The creation of operational and organizational methods of controlling the interference environment.

(4) The adoption of satisfactory protection criteria in the international Radio Regulations.

At the beginning of 1982 we have the following situation regarding the four needs:

(1) The RFI susceptibility of the Block IV receiver has been modelled for most of the CW cases. Models for the pulse interference (radar) cases do not yet exist.

(2) There is an operating computer program (DSIP2) to predict satellite interference. The program appears to provide the needed DSN protection in the sense that mission data is not seriously compromised by unexpected RFI from known satellite sources. The quantitative accuracy of predictions has not been determined.

(3) An effective Mojave Coordinating Group is managing the Goldstone environment. A similar arrangement does not exist at the overseas sites. A capability to predict RFI incidental to Fort Irwin operations near Goldstone is under development by an agency of the Department of Defense.

(4) The international Radio Regulations specify permissible levels of interference to deep-space downlinks. These levels were developed by JPL. They are not known to be inadequate although they are based on old analyses that do not consider current methods of coded telemetry.

In the ensuing sections of this report the reader will find discussion of each of these four needs and the status of efforts to satisfy them.

II. Susceptibility of DSN Earth Stations to RFI

In the development of DSN earth station receivers, the traditional emphasis has been on maximum sensitivity in an environment free of RFI. Indeed, the station sites were chosen to provide a quiet environment. With the increase in interference episodes, it became necessary to understand how the receiver performance is degraded by the presence of unwanted signals. In this section we consider JPL modelling of RFI susceptibility. Similar work by the Electromagnetic Compatibility Analysis Center (ECAC), a DOD agency, is being done in connection with Army operations at Fort Irwin near Goldstone. This work will be discussed in Section IV.

A. JPL Susceptibility Models

A susceptibility model is a mathematical expression that describes the response of a receiver to an interfering signal. For example, a particular interfering signal may result in an increased bit error rate for the desired telemetry signal from deep space. The model allows calculation of the change in bit error rate, provided the characteristics of the interference are known.

Because DSN receivers are complex, theoretical analysis of their behavior usually involves mathematical simplifications or idealizations. Independent verification of the analytic expressions is therefore necessary. This may be accomplished by laboratory or field testing under controlled conditions. The verified susceptibility models may be used:

(1) To analyze potential and experienced RFI.

(2) To enable the creation of operational RFI prediction capability.

(3) To provide the basis for interference protection criteria to the international Radio Regulations.

B. Status of JPL Modelling

The DSN Block IV receivers have been chosen for analysis primarily because they are associated with the 64-m antennas that are used when maximum sensitivity is required. Verification of the models has been accomplished by means of testing in the Telecommunications Development Laboratory. The tests involve measurement of RFI effects under controlled conditions of desired and interfering signals. Results of these tests are compared with effects predicted by the theoretical analysis. The analytic modelling has so far been accurate enough so that numerical adjustment (curve fitting) has not been necessary and is not done.

Modelling efforts to date have concentrated on CW interference. References 1-4 discuss this work. Current status of modelling is described in detail in Ref. 5. The CW susceptibility models provide a base for future study and modelling of the effects of pulse and noiselike interference. The relationship between the JPL models and the existing computer program for predicting RFI from satellites will be discussed in Section III.

An important motivation for the study of RFI susceptibility is the determination of acceptable levels of interference. These levels are specified in the Radio Regulations, as discussed further in Section V. The specification of levels of permissible interference implies an acceptable degradation with respect to the performance in the absence of interference. Permissible interference has been taken to be the amount that results in 1 dB receiver gain compression due to saturation, 15 deg phase jitter in the carrier tracking loop, and/or 1 dB degradation of telemetry performance. These values are somewhat arbitrary. The gain compression limitation is particularly tenuous in that the resulting effects on data quality have not been quantified. In addition, signals strong enough to cause gain compression have also been observed to generate spurious signals, but this effect has not yet been modelled.

III. Satellite RFI Prediction

An important class of interference is that coming from earth-orbiting satellites. Some of these operate in bands used for deep-space communications downlinks, or in adjacent bands. These satellites come within view of DSN earth stations in a regular, predictable way. It is therefore possible to determine in advance the times at which RFI may occur. To make RFI predictions, it is necessary to know the satellite orbits, deep-space mission trajectories, characteristics of the satellite signals, and the susceptibility of the DSN receivers.

The recurring nature of satellite interference suggests that an automated analysis program could be used to predict RFI. A computer program called Deep-Space Interference Prediction Program (DSIP2) has been developed for this purpose. The prediction program is in regular use to warn of potential RFI episodes. Corresponding action by the DSN depends on the consequences of the RFI that could occur. In some cases, satellite operators have been successfully requested to cease transmission during critical mission times. A general description of DSIP2 may be found in Ref. 6. Reference 7 is the DSIP2 Users Guide.

A. Development of DSIP2

The Deep-Space Interference Program, DSIP2, predicts the time when satellite RFI will occur, and it predicts the effect of the RFI: degradation of telemetry performance, telemetry drop lock, or receiver (carrier tracking) drop lock. A necessary condition for interference to occur is that a satellite is in view of the station that is tracking a deep-space spacecraft.

The periods of potential interference are determined by DSIP2 from satellite and spacecraft time and position data computed by other separate programs. Tests for interference are then made for these periods. Six tests are made:

(1) Receiver interference: received power above a fixed threshold and frequency separation less than a fixed value.

(2) Receiver drop-lock, Type 1.

(3) Receiver drop-lock, Type 2.

(4) Telemetry drop-lock, Type 1.

(5) Telemetry drop-lock, Type 2.

(6) Telemetry SNR degradation.

A description of these tests may be found in Appendix A. Appendix B lists the equations that are in the RFI subroutine of program DSIP2. The mathematical models embodied in the several tests are based on the effects of CW interference. DSIP2 presumes that the effects of more complex signals may be related to the CW models by characterizing the interference in terms of a family of spectral lines, each of which has a particular frequency and amplitude. Each line is considered to be a CW signal, and DSIP2 calculates the RFI signal effect of each line. For RFI predictions it is therefore necessary to know the spectral nature of the interfering satellite signal. Data on these parameters is obtained from the operator of the satellite, or by measurement of the received signal. Where military classification is an issue, other special arrangements are made for RFI prediction.

Because verified analytic models were not available at the time of DSIP development, receiver susceptibility was characterized by means of empirical testing of the effect of CW interference. These tests and the associated expression of results in the form of mathematical equations were done circa 1977 and are described in Refs. 8 and 9. In essence, some general theoretical analysis was developed and expressed in terms of equations and curves. Experimental data was then compared to the curves. Where necessary, the equations were modified to more nearly match the test data by means of a curve fitting process. This curve fitting results in the sometimes strange numerical constants included in the equations.

The theoretical basis for the prediction equations in DSIP2 is particularly unsatisfying from an analyst's point of view. In connection with the telemetry tests, there is an allusion in Ref. 4 to an analysis of the phase lock loop (PLL) jump phenomenon (Ref. 10). The phenomenon refers to a PLL dropping lock to a desired signal and locking to a stronger interfering signal. Extensive examination of the applicability of the Ref. 10 analysis to DSN receivers reveals considerable theoretical difficulty.

The origins of the DSIP2 models for receiver drop lock are obscure and apparently unpublished. (The term "receiver drop-lock" refers to the phase lock loop that tracks the received carrier signal). The general form of the equations is like those used for telemetry, but the corresponding test data has not been documented, if it exists.

Although a case can be made that DSIP2 can't work very well because of its simplistic modelling, it has not been demonstrated that more elaborate modelling is required for DSN protection. What is specifically missing at the present time is a useful determination of the detail strengths and weaknesses of DSIP2 performance. Also missing is a specification of required performance of the prediction capability: time accuracy, false alarm rate, and the accuracy of predicted effects such as drop-lock or SNR degradation.

B. DSIP2 Evaluation

In September 1977 there was a review of DSIP program status. Statistics were presented that described the ability of DSIP2 to predict interference to the Viking Orbiter 2 from the ESA GEOS satellite. When no RFI was predicted, no RFI was observed. For 31 predictions of RFI there were 13 episodes observed. The predictions were thus quite conservative for this particular satellite-deep-space mission pair.

More recently (Ref. 6) it was reported that nine instances of Voyager telemetry drop-lock caused by a Cosmos satellite were correctly predicted by DSIP2. Out of 15 instances of Pioneer 10 telemetry or receiver drop-lock, 11 were correctly predicted by DSIP2. The incorrect predictions for the other 4 instances were said to be a result of incomplete signal characterization of the interfering Cosmos.

These statistics suggest that DSIP2 is conservative: there are many false alarms and (apparently) no missing alarms. It is also clear that the quality of signal characterization is a determinant of prediction accuracy. Although the satellite interference prediction program has been used for several years, only limited anecdotal evidence of performance exists. For meaningful evaluation that can lead to validation, improvement, or simplification of prediction, it will be necessary to test two aspects of DSIP2: (1) the ability to correctly determine the amplitude and frequency of interfering spectral lines, and (2) the ability to correctly determine the effect of the received interference.

The existing RFI reporting system does not meet the needs of DSIP2 validation. The reports refer primarily to observed RFI events. There is no explicit reference to predictions, and there is no characterization and reporting of received signals that may be present when predicted RFI is or is not observed. A well planned test of DSIP2 accuracy is needed. The requirements and methods of such a test are being examined.

C. JPL RFI Models and DSIP2

Modelling of RFI susceptibility and the development of DSIP2 began at approximately the same time. The modelling effort was based on the premise of developing an analytic expression that would directly relate input signals to RFI effects. The DSIP2 approach uses a spectral line characterization of input signals and depends upon tests of each line against CW susceptibility expressions. Because of these different approaches, the verified analytic models are not always directly and easily incorporated into DSIP2. It has been judged that such incorporation should wait for a detailed evaluation of DSIP2 performance.

IV. Operational and Organizational Methods

The rising trend of RFI incidents at Goldstone was related to rising military activity in the surrounding area. Goldstone is situated within an Army training area and surrounded by other military reservations. The growing complexity of the electromagnetic environment was seen to be detrimental to DSN interests and of growing concern to other spectrum users in the extended Goldstone area. In recognition of the need for environmental control, a memorandum of understanding (Ref. 11) between NASA and the Department of Defense was written. The MOU included provisions for an operational coordination group and for the exchange of necessary technical information. In this regard, JPL is obligated to provide data suitable for interference calculations by the Electromagnetic Compatibility Analysis Center (ECAC), a contractor-operated facility for the Department of Defense.

The Mojave Coordinating Group has been operating for the last few years and is probably the single most effective mechanism for protecting the DSN stations at Goldstone. Since the group came into being, the trend of actual RFI to the DSN has been dramatically reversed. Incidental to the greatly expanded training activity being planned for the Army's Fort Irwin, ECAC undertook the development of RFI prediction capability, aimed in part at protecting Goldstone operations from the more intense potential for RFI.

A. ECAC Modelling

At the time that ECAC began the development of RFI prediction capability for Fort Irwin, a suitable mathematical model of DSN susceptibility did not exist. ECAC has therefore been working on model development based on detailed circuit and specification data on the Block IV receivers. This data was supplied by JPL. The ECAC effort parallels in time the JPL work on RFI models but has followed a somewhat different analytic approach.

From time to time JPL has been invited to comment on the ECAC reports describing their model development. The difficulty is that the analytic models require either laboratory or field verification. ECAC cannot do the laboratory testing since they do not have the requisite DSN equipment. In the absence of such testing, the only alternative is a comparison of trial predictions made by ECAC with predictions using the verified JPL models and/or DSIP2. JPL requested early in 1981 that ECAC provide trial predictions for selected CW cases, but these have not yet been received.

B. ECAC/Fort Irwin RFI Prediction

ECAC expects to manage the Fort Irwin environment by means of various models and analysis programs resident in an on-site computer. Utilizing predicted data on DSN operations (mission criticality, antenna pointing, signal level, etc.) the corresponding RFI potential of Fort Irwin exercises using many types of radio equipment would be analyzed.

The ultimate use of RFI predictions by ECAC would be to control the scheduling of Fort Irwin operations, to influence the selection and use of radio equipment in the area, and to influence DSN operations where possible. Experience will show whether elaborate or simple models are needed for RFI effective control vis-a-vis the Goldstone stations. One simple approach would be to cease operation of certain equipment during critical DSN mission phases at times when DSN elevation angles are below a selected value. This kind of control needs only operational data since the necessary criteria can be determined by analysis done in advance. ECAC tends to think of more elaborate schemes involving detailed real-time information transfer from Goldstone via hardline or microwave: received signal strength, antenna pointing, data mode, etc. The objective of this complicated approach is to maximize the freedom for Fort Irwin operations.

V. International Protection

The international Radio Regulations (Ref. 12) govern the use of the radio frequency spectrum. The Regulations specify methods and procedures by which the potential for interference is avoided or managed. To provide interference protection for various radio services, maximum permissible levels of interference are listed. The current values for deep-space receiving earth stations are based on analysis done at JPL circa 1968 (Ref. 13). The internationally adopted values of permissible interference power also serve JPL and NASA frequency managers in negotiations with other domestic agencies.

Current values of permissible interference as listed in the Regulations are based on an old analysis that does not consider coded telemetry. A more modern determination of permissible interference power is lacking, and hence the possibility of inadequacy of existing values of permissible interference cannot be determined. The protection afforded by the current international Radio Regulations is not known to cause problems for deep-space downlinks.

VI. Summary Assessment and Expected Future Work

In the foregoing sections we have discussed some history and status of four aspects of RFI analysis and prediction:

(1) Modeling

(2) Prediction

(3) Operational management

(4) Regulations

A. Model Development

The objectives of modelling remain valid:

(1) Support the detailed analysis of specific RFI situations.

(2) Provide for RFI prediction, both automatic and manual.

(3) Establish levels of permissible interference.

Continued JPL modelling is applicable to providing capability for RFI analysis and for providing improvements to the prediction program DSIP2. Although much of this report has dealt with DSIP2, it should be remembered that there is a more general class of analysis regarding actual and potential interference from a wide variety of sources other than earth-orbiting satellites.

The largely completed work on CW modeling sets the stage for consideration of pulse interference. Several approaches to analysis and modelling are possible, and the results of DSIP2 performance evaluation (Sec. VI-B) may affect the final selection. A likely approach is a continuation of the philosophy of developing models that use direct mathematical expression of input signals rather than the spectral line approach of DSIP2. The direct expression method is usually more general and can be expected to handle signals not amenable to the CW spectral line approach.

If DSIP2 evaluation shows that the empirical CW models themselves need improvement, the JPL analytic CW models should be utilized. It is presently intended that several approaches to pulse modelling will be explored. DSIP2 evaluation will provide additional information to guide future work.

B. RFI Prediction

Incorporated in the satellite RFI prediction program, DSIP2, are a number of assumptions:

(1) It is assumed that an interfering signal may be characterized by a set of spectral lines, each line being equivalent to a CW signal. Implicit in this assumption is signal duration that is long with respect to the various time constants in the receiving system. For some kinds of pulse signals this condition may not be met.

(2) It is assumed that the effect of each spectral line may be determined by models based on analysis and test of

receiver response to CW signals. Implicit in this assumption is a relatively stationary spectrum, in terms of amplitude and frequency, with respect to the receiver time constants. Frequency hopping and chirp signals as well as other complex modulation do not fit this assumption.

(3) It is assumed that drop-lock predictions may be based on tests for each spectral line; the cumulative effect of several lines need not be considered. The basis for this assumption has not been explained.

(4) It is assumed that the prediction program is operationally appropriate. The effect of high false alarm rate has not been determined. It is not known if the RFI criteria could be adjusted to reduce the false alarm rate without creating a missed alarm rate.

As discussed in the section on DSIP2 evaluation, it is timely and important to assess the actual performance of the program. A simple statistical summary of prediction vs experience is interesting but not sufficient. Several questions need to be answered:

(1) Are the predicted interference spectra actually present in the receiver?

(2) Do the RFI effects actually encountered reflect the prediction that would be made on the basis of the actual interference spectra?

(3) Is the basic approach of spectral analysis with CW models the correct one for further development?

It is planned that a field test at a selected station will be designed and completed, utilizing sufficient instrumentation to acquire the needed data. The results of these tests would be used to guide further model development, program improvement, or the adoption of different RFI threshold criteria.

The accuracy of DSIP2 predictions is critically dependent on knowledge of trajectory parameters (position, velocity, time) of each satellite and spacecraft pair being considered. It is also necessary to know the particular spacecraft communications mode that will be used during the period of potential RFI. This is because the interference prediction is related to the strength and modulation characteristics of the received spacecraft signal. The telemetry data rate and the presence or absence of ranging modulation affect the calculations.

An intrinsic difficulty of RFI prediction is that the circumstances assumed for calculation purposes may not actually exist at the time that the RFI is predicted to occur. The timeliness of prediction, the number of different calculations that should be made in order to include all likely or possible spacecraft modes, and the criteria concerning the list of satellites to be considered are important factors in the effectiveness of DSIP2. In addition to the assessment of the RFI calculations themselves, these additional factors deserve consideration when deciding the course of future development or prediction capability.

C. Operational Management

The operational management of the DSN RFI environment is believed to be well in hand. A detailed description of the organizations and methods of management is beyond the intended scope of this report and will not be treated further.

The DSN susceptibility modelling by ECAC, done in support of their Fort Irwin RFI management responsibility, does deserve comment. Continuation of this effort is not recommended. It is the author's opinion that the actual RFI environment that will attend expanded Fort Irwin operations is not well enough understood to justify an elaborate, computerized, near-real-time analysis capability. (It is of course possible to postulate an impossibly difficult environment.) What is needed is the ability to locate and characterize those sources that actually cause interference to the DSN. Experience with the environment will confirm or deny the possibility of simple control procedures, such as minimum elevation angle constraints, that will permit economical control of interference. It may be that computerization can be limited to simple a priori total power and path loss calculation with respect to a level of permissible interference.

D. Radio Regulations

To continue the protection of deep-space telecommunications links it is essential that levels of permissible interference be accurately stated in the Radio Regulation. It is therefore planned that a report be prepared to modernize the analysis that supports the regulatory process. Of particular importance is the inclusion of coded telemetry susceptibility analysis. The report would be submitted to the International Radio Consultative Committee (CCIR) for adoption.

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Appendix A

Description of DSIP2 RFI Models[1]

I. Introduction

In this appendix we examine the equations and tests for RFI as they are implemented in DSIP2. Appendix B is taken from a JPL internal document and is a concise listing of these, from the point of view of a software engineer.

Subroutine CIANSP in DSIP2 makes six tests for interference:

(1) Receiver interference: received power above a fixed threshold and frequency separation less than a fixed value.

(2) Receiver drop-lock, Type 1.

(3) Receiver drop-lock, Type 2.

(4) Telemetry drop-lock, Type 1.

(5) Telemetry drop-lock, Type 2.

(6) Telemetry SNR degradation.

For each of these tests there are equations that are used to make the necessary calculations and decisions that lead to a prediction to RFI.

The calculations and tests are made with respect to the individual spectral lines that characterize the received signals. The power and frequency of each spike (spectral line) are determined and used in the various tests for RFI.

II. The Received Signal

It is important to remember that the accuracy of DSIP2 predictions is totally dependent on the knowledge and assumptions made regarding the strength of the interfering signal. The radiated amplitude and frequency of each spectral line must be specified for input to DSIP2. The amplitude is normally expressed as an e.i.r.p. that accounts for the transmitted power and main beam antenna gain. Calculations using these values of e.i.r.p. are therefore worst case in the sense that the satellite antenna may not always point directly at the earth station.

[1]The material presented in this appendix is based on a more extensive analysis by Ali Salmasi and his contribution is gratefully acknowledged.

III. Receiver Interference

Receiver interference is judged to occur if two conditions are met as shown in formula[2] F13:

$$\Delta f^*_{c_i} - 1000 \text{ Hz} \leq 0,$$

and

$$I_{e_i} \geq -175 \text{ dBm}$$

Δf^*_{ci} is the frequency separation between an interfering spike and the carrier frequency of the desired signal, taking into account doppler shifts, as computed by F11. The 1000-Hz criterion is the result of experimental tests (Ref. 8).

The −175 dBm criterion is related to the sensitivity of the Block IV receiving system. For a desired signal that results in normal threshold conditions, a CW signal less than −175 dBm is predicted to be free of RFI effects.

The power of a received spike is calculated from F8:

$$I_{e_i} = P_{SAT_i} - L_{S_{SAT}} + G_{A_{SAT}} - MGR$$

The transmitted power level of the ith spike, P_{SAT_i}, is the e.i.r.p in the direction of the earth station. This value actually varies as a function of the pointing direction of the satellite antenna. For DSIP2, the worst-case main beam e.i.r.p. is used. $L_{S_{SAT}}$ is found by F2 and gives a value for free space loss. It does not include atmosphere loss effects and hence is conservative in the sense of giving maximum interference power. $G_{A_{SAT}}$ is the earth station antenna gain in the direction of the satellite and is determined by F1, which gives a simple envelope relationship between gain and angle off boresight. The envelope method is conservative.

MGR is an estimate of the reduction in maser gain as a function of received power. MGR is found from an empirical formula, F5, which was derived from test data and which depends on the total received power level I_e. I_e is given by F4 and once again is e.i.r.p. in the direction of the DSS. Notice that $MGR = 0$ for interference power less than −90 dBm.

[2]Formulas referred to in this appendix may be found in Appendix B.

Notice also that *MGR* does not depend on frequency. More recent studies have shown that maser/receiver saturation *is* a function of frequency. The DSIP2 modelling of saturation could be modernized.

IV. Receiver Drop-Lock

The carrier tracking loop in a DSS receiver normally is locked to a desired signal. If interference causes the loop to no longer track the desired signal, drop-lock is said to have occurred. DSIP2 predicts two kinds of drop-lock: jump to the interfering signals, and loss of desired signal by suppression.

A. Receiver Drop-Lock, Type 1 (Jump)

Type 1 drop-lock is based on the jump phenomenon observed in some phase-locked loop (PLL) receiver systems. If such a PLL is initially tracking a desired signal, the loop will jump to an interfering signal that is sufficiently near in frequency and strong in power. In DSIP2, the tests for Type 1 drop-lock are given by F15:

When $\Delta f_{c_i}^* < B_e$, the test for drop-lock is

$$I_{e_i} - (P_c - MGR) \geqslant 0$$

When $\Delta f_{c_i}^* \geqslant B_e$, the test for drop-lock is

$$I_{e_i} - (P_c - MGR) - 20 \log\left(\frac{\Delta f_{c_i}^*}{B_e}\right) \geqslant 0.$$

where B_e is the noise bandwidth of the carrier tracking loop. In DSIP2, B_e is set at a fixed value of 12 Hz, which is a typical value for DSN receivers operating near threshold. The loop bandwidth is actually a function of signal level, becoming wider as the level increases. P_c is calculated by F14 and is the carrier component of the total power of the desired signal; P_c depends upon the modulation index and is related to the telemetry mode.

For the case where the interfering spectral line is separated from the desired carrier by an amount less than the loop bandwidth, drop-lock is predicted when the line is equal to or stronger through the desired carrier signal. For the case where the interfering line is separated from the desired carrier by an amount equal to or greater than the loop bandwidth, drop lock is predicted when the line less an amount proportional to the frequency separation is equal to or greater than the desired carrier signal.

These equations were developed from empirical data and, perhaps, an interpretation of the analysis presented in Ref. 7.

B. Receiver Drop-Lock, Type 2 (Maser Saturation)

If a Type 1 receiver drop-lock is not predicted, the test of F16 is made. In this test, Type 2 drop-lock is predicted if the carrier power is reduced by maser gain reduction (*MGR*) to a value less than the noise power in the tracking loop bandwidth. This test is independent of frequency separation and applies to the case where the total interference power exceeds -90 dBm; at lower power there is no *MGR*.

The Type 2 model does not consider a more general analysis of receiver saturation and corresponding effects on performance. More complete modelling is now possible.

V. Telemetry Drop-Lock

The telemetry demodulation and detection process in DSS receivers makes use of phase-locked loops. These track the subcarrier frequency and the symbol and bit rates. Based on experimental data, empirical expressions for predicting telemetry drop-lock were developed. Two types of telemetry drop-lock are predicted by DSIP2: Type 1, jump, and Type 2, SNR degradation.

A. Telemetry Drop-Lock, Type 1 (Jump)

The tests for telemetry Type 1 drop-lock are given by F30:

When $\Delta_{f_{nsc_i}} < SR$, the test for drop-lock is

$$1.3 \; [P_{I_i} - (P_D - MGR) - 3] \geqslant 0.$$

When $\Delta f_{n_{sc_i}} \geqslant SR$, the test for drop-lock is

$$1.3 \; [P_{I_i} - (P_D - MGR) - 3] - 20 \log \left(\frac{\Delta f_{n_{sc_i}}^*}{SR}\right) \geqslant 0.$$

where $\Delta f_{n_{sc_i}}$ is the frequency difference between a particular spike and a particular subcarrier harmonic in the desired signal. It has been shown that a CW signal at or near a subcarrier harmonic can cause telemetry drop-lock. The effective interference power of the CW line is reduced for the higher order harmonics and P_D is computed by F19 to account for this. P_D is the data power in the desired signal and is calculated by F29.

These expressions were developed by assuming a mathematical model and then modifying it to fit a set of test data points (Ref. 8). The assumed model is of the same general form presented in Ref. 10, which given an analysis of the PLL jump phenomenon for a particular set of conditions. Comparison of Ref. 10 with equations in F30 shows that the DSIP2 implementation differs in detail. The numerical constants in F30 are the result of curve fitting.

B. Telemetry Drop-Lock, Type 2 (Maser Saturation)

If a Type 1 telemetry drop-lock is not predicted, the following test is made:

$$SNR_{OUT} - \Delta SNR_T + 5\ \text{dB} \geqslant 0$$

where SNR_{OUT} is found by Formulas 32, 31 and 28. This test is based on the performance of the symbol synchronizer assembly (SSA), wherein a *SNR* greater than −5 dB must be present to achieve an in-lock condition.

VI. Telemetry SNR Degradation

Interference that is not strong enough to cause drop-lock may nevertheless result in degraded telemetry performance. The effect of degraded performance is an increase in the data error rate. For a given telemetry system there is a relationship between signal-to-noise ratio (*SNR*) and the error rate. DSIP2 predicts the change in *SNR* due to interference. The predicted change is given by F28:

$$\Delta SNR_T = \Delta SNR + MGR$$

where

ΔSNR_T is the total change in *SNR*

ΔSNR reflects the noise added by the interference

MGR is the reduction in signal caused by maser saturation.

The degradation in *SNR* caused by the interference is given by F27:

$$\Delta SNR = 10 \log \left(\frac{T_R + T_s}{T_s} \right)$$

where

T_R is the cumulative noise temperature for all interfering spikes.

T_s is the system noise temperature in the absence of interference.

The determining concept in this formulation is that the effect of a set of CW spikes can be represented in terms of a change in system noise temperature. References 8 and 9 present an analytic development using this premise. The relationship between CW interference and the corresponding change in noise temperature was determined experimentally. Using theoretical curves of bit error rate as a function of *SNR*, and experimental data on bit error rate as a function of interference, the expressions of F24 and F25 were derived by curve fitting.

The first experimental test data was obtained for a bit rate of 2000 bps and for the case where the interfering spike was coincident with the frequency of the telemetry subcarrier. The relationship between interference power and noise temperature was then determined.

F25 gives the noise temperature for a single spectral line:

$$T_{R_i} = \left[\left({}_{10}\ 821\, e^{0.0421 P^*_{I_i}} \right)^2 + 40^2 \right]^{1/2} - 39.5$$

where

T = is the noise temperature due to the *i*th spike

P_I is the power in the *i*th spike

An observed effect is that a CW spike at or near the subcarrier frequency, or its harmonics, will cause interference related to the frequency separation and the harmonic number. To account for this mechanism, as well as to accommodate symbol rates other than 2000 bps, additional test data and curve fitting gave Formula 24, which relates several factors:

P_I, the interference power to be used in Formula 25

I_e, the interference power of a spike found by Formula 8

N_i, the subcarrier harmonic number found by Formula 18

P_D, the total data power of the desired signal as found by Formula 29

SR, the symbol rate

$\Delta f^*_{nSC_I}$, the frequency separation between the subcarrier harmonic and interfering spike as found by Formula 21

The reader is urged to examine F25 and its subordinate equations in Appendix B. They are excellent examples of the result of curve fitting that forces a mathematical expression to fit experimental data by means of peculiar arithmetic constants.

The telemetry *SNR* degradation model described above can be expected to predict interference for the conditions implicit in the experimental test and subsequent curve fitting. Regardless of the analytic assumptions that were made, the several formulas were forced to fit these data. The problem is that other conditions may require different values for the constants in the formulas, or different formulas. For example, the test data used to develop the existing model was taken with an uncoded data stream. For each type of coded data, there is a different curve relating error rate and *SNR*. DSIP2 does not account for this difference.

Finally, there is a general test for telemetry degradation. Interference is judged to be present when

$$\Delta SNR_T \geqslant 0.5 \text{ dB}.$$

Appendix B
Interference Tests and RFI Formulas

I. Interference Tests

The following six interference functions are the basic tests made by subroutine CIANSP to determine if radio frequency interference exists, the form it takes and the telemetry modes impacted at a given point in time:

1. Receiver Interference Function (Formula F13, see Part II for this and other formulas)

If for one or more satellite spectrum spikes it is true that:

$$\Delta f^*_{c_i} - 1000 \text{ Hz} \leqslant 0 \quad .\text{AND}. \, I_{e_i} \geqslant -175 \text{ in dBm}$$

then receiver interference is judged to have occurred and the flag BRI = .TRUE. is set at line 212 of CIANSP. These conditions are a necessary part of the requirements for receiver drop-lock of the first type. The event of receiver interference occurring is recorded in the bits of array IISW for the subcarrier bit rate mode being tested if receiver drop-lock does not occur.

$\Delta f^*_{c_i}$ = frequency separation between a spike and the spacecraft carrier as received at the antenna and adjusted for worst-case trajectory errors (Formula F11) in Hz and

I_{e_i} = effective power level of a spike (Formula F8) in dBm

2. Receiver Drop-Lock Function for the Jump Phenomenon (First Type) (Formula F15)

If receiver interference occurs for a subcarrier bit rate mode, its spikes are checked for the following conditions:

$$I_{e_i} - (P_c - MGR) - 20 \log \left(\frac{\Delta f^*_{c_i}}{B_e} \right) \geqslant 0 \text{ for } \Delta f^*_{c_i} \geqslant B_e \text{ in Hz}$$

or

$$I_{e_i} - (P_c - MGR) \geqslant 0 \text{ for } \Delta f^*_{c_i} < B_e \text{ in Hz}$$

If these conditions also hold for one or more spikes, receiver drop-lock of the first type has occurred, the flag BRDL = .TRUE. is set at line 313 of CIANSP and the appropriate bits of array IISW are set for this bit rate mode.

P_c = downlink carrier signal power level (Formula F14) in dBm

MGR = maser gain reduction (Formula F5) in dB and

B_e = receiver RF loop noise bandwidth for the station = 12 Hz

3. Receiver Drop-Lock Function for Maser Saturation (Second Type) (Formula F16)

If receiver drop-lock of the first type does *not* occur for a subcarrier bit rate mode, the following test is made:

$$P_c - MGR + 198.6 - 10 \log B^*_e - 10 \log T_s \leqslant 0.$$

If this condition holds, receiver drop-lock of the second type has occurred, the flag BDRL = .TRUE. is set at line 323 of CIANSP and the appropriate bits of array IISW are set for this bit rate mode. The bit setting is the same in IISW for both types of receiver drop lock.

T_s = antenna cold sky temperature (K) for the station being checked and

B_c^* = receiver RF loop noise threshold for the station = 12 Hz.

4. Telemetry Drop-Lock Function of the First Type (Formula F30)

If receiver drop lock of either type does not occur for a subcarrier bit rate mode, the following test is made for each satellite spectrum spike:

$$P_{I_i} \geqslant -175 \text{ dBm .AND. } 1.3\ [P_{I_i} - (P_D - MGR) - 3]\ \ -20 \log \left(\frac{\Delta f^*_{n_{sc_i}}}{SR} \right) \geqslant 0 \text{ for } \Delta f^*_{n_{SC_i}} \geqslant SR$$

or

$$P_{I_i} \geqslant -175 \text{ dBm .AND. } 1.3\ [P_{I_i} - (P_D - MGR) - 3]$$

$$\text{for } \Delta f^*_{n_{SC_i}} < SR.$$

If this condition holds for one or more spikes, telemetry drop-lock of the first type has occurred, the flag BTDL = .TRUE. is set at line 386 of CIANSP and the appropriate bits of array IISW are set for this bit rate mode.

P_{I_i} = power quantity for a spike (Formula F19) in dBm,

P_D = total data power (Formula F29) in dBm,

$\Delta f^*_{n_{SC_i}}$ = frequency separation between the ith spike and the N_ith subcarrier harmonic as adjusted for worst-case trajectory errors (Formula F21) in Hz,

SR = bit rate mode symbol rate (Formula F23) in bits per second.

5. Telemetry Drop-Lock Function of the Second Type

If neither receiver drop-lock nor telemetry drop-lock of the first type occurs for a subcarrier bit rate mode, the following test is made:

$$SNR_{OUT} - \Delta SNR_T + 5 \text{ dB} \leqslant 0.$$

If this condition holds, telemetry drop lock of the second type has occurred, the flag BTDL = .TRUE. is set at line 410 of CIANSP and the appropriate bits of array IISW are set for this bit rate mode. The bit setting is the same in IISW for both types of telemetry drop-lock.

SNR_{OUT} = output signal-to-noise ratio (Formula F32) in dB and

ΔSNR_T = total signal-to-noise degradation (Formula F28) in dB.

6. Signal-to-Noise Ratio Degradation Function

If none of the above types of drop-lock occurs for a subcarrier bit rate mode, the following test is made:

$$\Delta SNR_T \geqslant 0.5 \text{ dB}.$$

If this condition holds, signal-to-noise ratio degradation has occurred, the flag BDSNI = .TRUE. is set at line 414 of CIANSP and the appropriate bits of array IISW are set for this bit rate mode.

II. RFI Formulas

The RFI formulas referred to in the preceding discussion are specified below as they are implemented in the subroutine CIANSP code:

1. F1: Antenna Gain, G_A,

   For 26 meter S-band stations 11, 12, 13, 42, 44, 61 and 62:

$$G_A = \begin{cases} 53.3 \text{ dB} & \\ 32 - 25 \log \Delta & \text{for} \\ -10 & \end{cases} \begin{cases} 0° \leqslant \Delta \leqslant 0.14°, \text{ or} \\ 0.14° < \Delta \leqslant 45°, \text{ or} \\ 45° < \Delta . \end{cases}$$

   For 64 meter S-band stations 14, 43 and 63:

$$G_A = \begin{cases} 61.7 \text{ dB} & \\ 32 - 25 \log \Delta & \text{for} \\ -10 & \end{cases} \begin{cases} 0° \leqslant \Delta \leqslant 0.065°, \text{ or} \\ 0.065° < \Delta \leqslant 45°, \text{ or} \\ 45° < \Delta . \end{cases}$$

   Δ = cone angle (°) between the antenna/spacecraft downlink direction and the antenna/satellite direction

2. F2: Space Loss, L_S in dB,

   $L_S = 32.45 + 20 \log f + 20 \log \rho,$

   f = spike frequency or carrier frequency in MHz and

   ρ = station-satellite or station-spacecraft distance in km.

3. F4: Total Effective Interference Power I_e in dBm,

$$I_e = P_{OUT_{SAT}} - L_{S_{SAT}} + G_{A_{SAT}},$$

   $P_{OUT_{SAT}}$ = satellite total power in dBm,

   L_{SAT} = space loss for satellite using frequency of first spike as the input frequency in dB and

   $G_{A_{SAT}}$ = antenna gain with respect to the spacecraft-to-satellite cone angle separation in dB.

4. F5: Maser Gain Reduction, MGR, in dB,

$$MGR = \begin{cases} 25.106 * \left[1 + \dfrac{(I_e + 90)^2}{441.378}\right]^{1/2} - 0.131 * I_e - 36.644, & \\ \text{or} & \text{for } I_e > -90 \text{ dBm} \\ 0 & \text{for } I_e \leqslant -90 \text{ dBm.} \end{cases}$$

5. F6: Transmitter Frequency, TX, in Hz,

$TX = 96 * TSF$ and

$TSF =$ transmitter synthesizer frequency in Hz,

6. F7: Carrier Frequency Received at Antenna, f_c', in Hz,

$$f_c' = TX \left(1 - \frac{\dot{\rho}_u}{c}\right) \left(\frac{240}{221}\right) \left(1 - \frac{\dot{\rho}_d}{c}\right),$$

$\dot{\rho}_u$ = uplink range rate in km/s,

$\dot{\rho}_d$ = downlink range rate in km/s and

c = speed of light in km/s.

7. F8: Effective Power Level of a Spike, I_{e_i}, in dBm,

$$I_{e_i} = P_{SAT_i} - L_{S_{SAT}} + G_{A_{SAT}} - MGR \text{ and}$$

P_{SAT_i} = transmitted power level of the ith spike in dBm.

8. F9: Frequency of a Spike as Received at Antenna, f_{I_i}', in Hz,

$$f_{I_i}' = f_{I_i} \left(1 - \frac{\dot{\rho}_{SAT}}{c}\right),$$

f_{I_i} = satellite spike frequency in Hz and

$\dot{\rho}_{SAT}$ = antenna/satellite slant range rate in km/s.

9. F10: Frequency Separation Between a Spike and the Carrier as Received at Antenna, Δf_{c_i}, in Hz,

$$\Delta f_{c_i} = \left\| f_{I_i}' - f_c' \right\| .$$

10. F11: Spike/Carrier Frequency Separation as Adjusted for Worst-Case Trajectory Errors, $\Delta f_{c_i}^*$, in Hz,

$$\Delta f_{c_i}^* = \begin{cases} \Delta f_{c_i} - \epsilon_{\Delta f_c} & \text{for } \epsilon_{\Delta f_c} < \Delta f_{c_i} \\ \text{or} & \\ 10^{-100} & \text{for } \epsilon_{\Delta f_c} \geq \Delta f_{c_i} \end{cases}$$

$\epsilon_{\Delta f_c}$ = frequency separation adjustment for worst-case trajectory errors in Hz

$$\epsilon\Delta f_c = f'_{I_i} * \frac{\dot{\rho}_{WC}}{c} + TX * \left(\frac{240}{221}\right) * \left[\left(1 - \frac{\dot{\rho}_u}{c}\right)\frac{\dot{\rho}_{WC}}{c} + \left(1 - \frac{\dot{\rho}_d}{c}\right)\frac{\dot{\rho}_{WC}}{c}\right]$$

and

$\dot{\rho}_{WC}$ = worst-case antenna/spacecraft range rate error in km/s.

11. F12: Receiver Peak Value Function for a Spike, P_{r_i}, in dBm,

$$P_{r_i} = \begin{cases} I_{e_i} - 20 \log \Delta f^*_{c_i} & \text{for } \Delta f^*_{c_i} \geqslant 12 \text{ Hz.} \\ \text{or} & \\ I_{e_i} & \text{for } \Delta f^*_{c_i} < 12 \text{ Hz.} \end{cases}$$

Note: p_{r_i} is not required as part of input to any essential interference computations but is computed as information for the user as regards the most potent spike at this time point and station.

12. F13: Receiver Interference Function

The BRI receiver interference flag is set = .TRUE. when for one or more spikes *both* of the following are true:

$$\Delta f^*_{c_i} - 1000 \text{ Hz} \leqslant 0 \text{ .AND. } I_{e_i} \geqslant -175 \text{ dBm.}$$

13. F14: Downlink Carrier Signal Level, P_c, in dBm,

$$P_c = \begin{cases} P_{OUT_{SC}} + 20 \log (\cos \theta) + 20 \log (\cos \theta^*) - L_{S_{SC}} + G_{A_{SC}} - L_0 \\ \quad \text{for a dual subcarrier} \\ \text{or} \\ P_{OUT_{SC}} + 20 \log (\cos \theta) - L_{S_{SC}} + G_{A_{SC}} - L_0 \\ \quad \text{for a solo subcarrier.} \end{cases}$$

$P_{OUT_{SC}}$ = spacecraft transmitter output power level in dBm,

0 = modulation index for current bit rate mode in deg,

$\theta *$ = modulation index for dual subcarrier in deg,

$L_{S_{SC}}$ = space loss for the spacecraft from F2 using carrier frequency f_c' in dB,

$G_{A_{SC}}$ = antenna gain for the spacecraft from F1 with $\Delta = 0$ in dB and

L_0 = all other losses = 0.5 dB.

14. F15: Receiver Drop-Lock Function for the Jump Phenomenon (First Type)

The BDRL receiver drop-lock flag is set = .TRUE. when for one or more spikes and the current bit rate mode:

$$\begin{cases} BRI = \text{.TRUE. .AND.}\ I_{e_i} - (P_c - MGR) - 20 \log \left(\dfrac{\Delta f^*_{c_i}}{B_e} \right) \geq 0 \\ \text{for } \Delta f^*_{c_i} \geq B_e \text{ in Hz} \\ \text{or} \\ BRI = \text{.TRUE. .AND.}\ I_{e_i} - (P_c - MGR) \\ \text{for } \Delta f^*_{c_i} < B_e \text{ in Hz,} \end{cases}$$

B_e = receiver RF loop noise bandwidth for the station = 12 Hz.

15. F16: Receiver Drop-Lock Function for Maser Saturation (Second Type)

If receiver drop-lock of the first type does not occur for the current bit rate mode, nevertheless $BDRL$ = .TRUE. is set if:

$P_c - MGR - (-198.6 + 10 \log B_e^* + 10 \log T_s) \leq 0$ in dBm,

T_s = antenna cold sky temperature for the current station in K and

B_e^* = receiver RF loop noise threshold for the station = 12 Hz.

16. F17: Frequency Ratio for a Spike, w_i

$$w_i = \frac{\Delta f_{c_i}}{f_{SUBC}} \quad ,$$

f_{SUBC} = subcarrier frequency for the current bit rate mode in Hz.

17. F18: Subcarrier Harmonic Number for a Spike, N_i

$$N_i = \begin{cases} 1 \text{ for } 0 \leq w_i \leq 2 \text{ and} \\ w - 1 \text{ for } W - 2 < w_i \leq W \end{cases}$$

where $W = 4, 6, 8 \ldots$ any positive even integer above 2;

N_i = number of the subcarrier harmonic most affected by the ith spike.

18. F19: Power Quantity for a Spike, P_{I_i}, in dBm,

$$P_{I_i} = I_{e_i} - 0.94 * 20 \log N_i .$$

19. F20: Frequency Separation Between the ith Spike and the N_ith Subcarrier Harmonic, $\Delta f_{n_{SC_i}}$, in Hz,

$$\Delta f_{n_{SC_i}} = \begin{cases} \left\| f'_{I_i} - (f'_c + N_i * f_{SUBC}) \right\| & \text{for } f'_{I_i} \geqslant f'_c \\ \text{or} & \\ \left\| f'_{I_i} - (f_c - N_i * f_{SUBC}) \right\| & \text{for } f'_{I_i} < f'_c . \end{cases}$$

20. F21: Spike/Subcarrier Harmonic Frequency Separation as Adjusted for Worst-Case Trajectory Errors, $\Delta f_{n_{SC_i}}$, in Hz

$$\Delta f^*_{n_{SC_i}} = \begin{cases} \Delta f_{n_{SC_i}} - \epsilon_{\Delta f_c} & \text{for } \epsilon_{\Delta f_c} < \Delta f_{n_{SC_i}} \\ \text{or} & \\ 10^{-100} & \text{for } \epsilon_{\Delta f_c} \geqslant \Delta f_{n_{SC_i}} . \end{cases}$$

21. F22: Telemetry Peak Value Function for a Spike, p_{t_i}, in dBm,

$$p_{t_i} = P_{I_i} - 20 \log \Delta f^*_{n_{SC_i}} .$$

Note: P_{t_i} is not required as part of input to any essential interference computations but is computed as information for the user as regards the most potent spike at this time point, bit rate mode and station

22. F23: Symbol Rate of the Current Bit Mode, SR, in bits per second,

$$SR = BR * m_{CODE} ,$$

BR = bit rate of the current bit rate mode and

m_{CODE} = telemetry code multiplier for the current bit rate mode.

23. F24: Quantity $P_{I_i}^*$ for a Spike in dBm,

$$P_{I_i}^* = \begin{cases} I_{e_i} - 0.94 * 20 * \log - 0.10 * (P_D - MGR + 141.) - 0.90 * 10 * \log\left(\frac{SR}{2000}\right) & \text{for } \frac{\Delta f_{n_{SC_i}}^*}{SR} \leqslant 1, \\ \text{or} & \\ I_{e_i} - 0.94 * 20 * \log N_i - 0.10 * (P_D - MGR + 141.) - 0.90 * 10 * \log\left(\frac{SR}{2000}\right) & \\ \quad - 0.90 * 20 * \log \left\{ \left[\text{Int}\left(\frac{\Delta f_{n_{SC_i}}^*}{SR}\right) + 0.5 \right] * \Pi \right\} & \text{for } \frac{\Delta f_{n_{SC_i}}^*}{SR} > 1, \end{cases}$$

P_D = total data power (F29) in dBm.

24. F25: Noise Temperature for a Spike, T_{R_i}, in K,

$$T_{R_i} = \begin{cases} \left[\left(821\, e^{0.421 P_{I_i}^*}_{10}\right)^2 + 40^2\right]^{1/2} - 39.5 & \\ \text{or} & \text{for } P_{I_i} \geqslant -175 \\ 0 & P_{I_i} < -175. \end{cases}$$

25. F26: Noise Temperature for All Spikes, T_R, in K,

$T_R = \sum_i T_{R_i}$ where $\sum_i$ indicates summation over all of the spikes for the current satellite.

26. F27: Signal-to-Noise Ratio Degradation, ΔSNR, in dB,

$$\Delta SNR = 10 \log\left(\frac{T_R + T_S}{T_S}\right)$$

27. F28: Total Signal-to-Noise Ratio Degradation, ΔSNR_T in dB,

$$\Delta SNR_T = \Delta SNR + MGR.$$

28. F29: Total Data Power, P_D, in dBm,

$$P_D = P_C + 20 \log(\tan\theta).$$

29. F30: Telemetry Drop-Lock Function (First Type)

If receiver drop-lock at either type does not occur for a bit rate mode but *both* of the following conditions hold for one or more spikes:

$$P_{I_i} \geqslant -175 \text{ dBm .AND. } 1.3\ [P_{I_i} - (P_D - MGR) - 3] - 20 \log \left(\frac{\Delta f^*_{n_{SC_i}}}{SR} \right) \geqslant 0 \quad \text{for } \Delta f^*_{n_{SC_i}} \geqslant SR,$$

or

$$P_{I_i} \geqslant -175 \text{ dBm .AND. } 1.3\ [P_{I_i} - P_D - MGR - 3] \quad \text{for } \Delta f^*_{n_{SC_i}} < SR,$$

then $BTDL$ = .TRUE. is set for this bit rate mode.

30. F31: Input Signal-to-Noise Ratio, SNR_{IN}, in dB,

$$SNR_{IN} = P_D - 10 \log SR - 10 \log T_S + 198.6.$$

31. F32: Output Signal-to-Noise Ratio, SNR_{OUT} in dB,

$$SNR_{OUT} = SNR_{IN} - SL,$$

where SL = system losses for the station = 0.5 dB.

32. Telemetry Drop-Lock Function for Signal-to-Noise Degradation

If neither receiver drop-lock nor telemetry drop-lock of the first type occurs for a bit rate mode, the following test is made:

$$SNR_{OUT} - \Delta SNR_T + 5 \text{ dB} \geqslant 0,$$

If all these conditions hold, $BTDL$ = .TRUE. is set for this bit rate mode.

33. Signal-to-Noise Ratio Degradation Function

If none of the several types of drop-lock occur for a bit rate mode the following condition is tested:

$$\Delta SNR_T \geqslant 0.5 \text{ dB}.$$

If this holds, $BDSNI$ = .TRUE. is set for this bit rate mode.